Rennovia ... a new path to sustainability

Production of Bio-based Chemicals from Renewable Feedstocks – an American Opportunity

Biomass 2011: Replace the Whole Barrel, Supply the Whole Market

National Harbor, Maryland, July 26th, 2011

Dr. Gary Diamond, VP Product Development

Rennovia Inc.

The US Chemical Industry

The American Chemical Industry – a Bedrock for US Manufacturing

- In the US, about 5% of each barrel of oil goes to petrochemicals, compared to about 70% to transportation fuels, yet the downstream value created is similar

- The US chemical industry contributes greatly to the US economy:
  - $720 B to the US economy (about 5% of GDP), including $170 B in exports
  - 800,000 (highly paid) direct jobs, plus over 4 million additional indirect jobs

- However, the US chemical industry is declining both in terms of total number of jobs (down from 980,000 in 1999), and global market share (27% in 1999 to 19% in 2009)

- Global mega-trends impacting the US chemical industry include:
  - Increasing competition from low-wage, low-capital countries in Asia
  - Petroleum feedstock-advantaged regions such as the Middle East

Source: American Chemistry Council

Bio-based Chemicals Production: an American Opportunity

- Compared with bio-fuels, bio-chemicals production provides higher value products, at smaller scale, with lower capital investment required

- A number of commodity-scale chemicals can potentially be produced from biomass at costs lower than current petrochemical technologies, without the need for mandates or subsidies

- Bio-based chemicals production, exploiting America's advantaged agricultural & forestry infrastructure, offers the opportunity for the US to regain global leadership in chemicals production

- A bio-based chemicals industry does not necessarily imply a reliance on biotechnology & fermentation

- Rennovia is adapting chemo-catalytic technology, already proven to be scalable and efficient in the refining & chemical industries, for the conversion of biorenewable feedstocks to today's key petrochemicals

Bio-based Chemicals Production: an American Opportunity

Advantaged Agricultural & Forestry Infrastructure

Cost Effective, Scalable, Conversion Technologies

Rennovia

Bio-based Chemicals Manufacturing Industry

Introduction to Rennovia

OVERVIEW

- Venture-capital backed company based in Menlo Park, CA
  - CEO Bob Wedinger – 25+ year veteran of the chemicals industry
  - Founders Tom Boussie and Vince Murphy – ex-Symyx Technologies
  - Key employees from BP, DuPont, Symyx, Engelhard, Sud-Chemie

MISSION

- Develop chemo-catalytic process technology for the production of existing major-market chemicals from renewable raw materials
- Focus on delivering fundamental cost advantage *vs*. incumbent petroleum-based processes
- Commercialize a multi-product pipeline

VISION

- To create a specialty chemical company that manufactures and markets renewable chemical products

Existing High-Value Chemicals from Renewable Feedstocks

Large Existing Markets

- Multiple large-volume product opportunities
- >$15B established markets for initial targets

Catalytic Chemical Processes

- Greater efficiency and scalability *vs*. fermentation
- Leverage existing chemical manufacturing assets

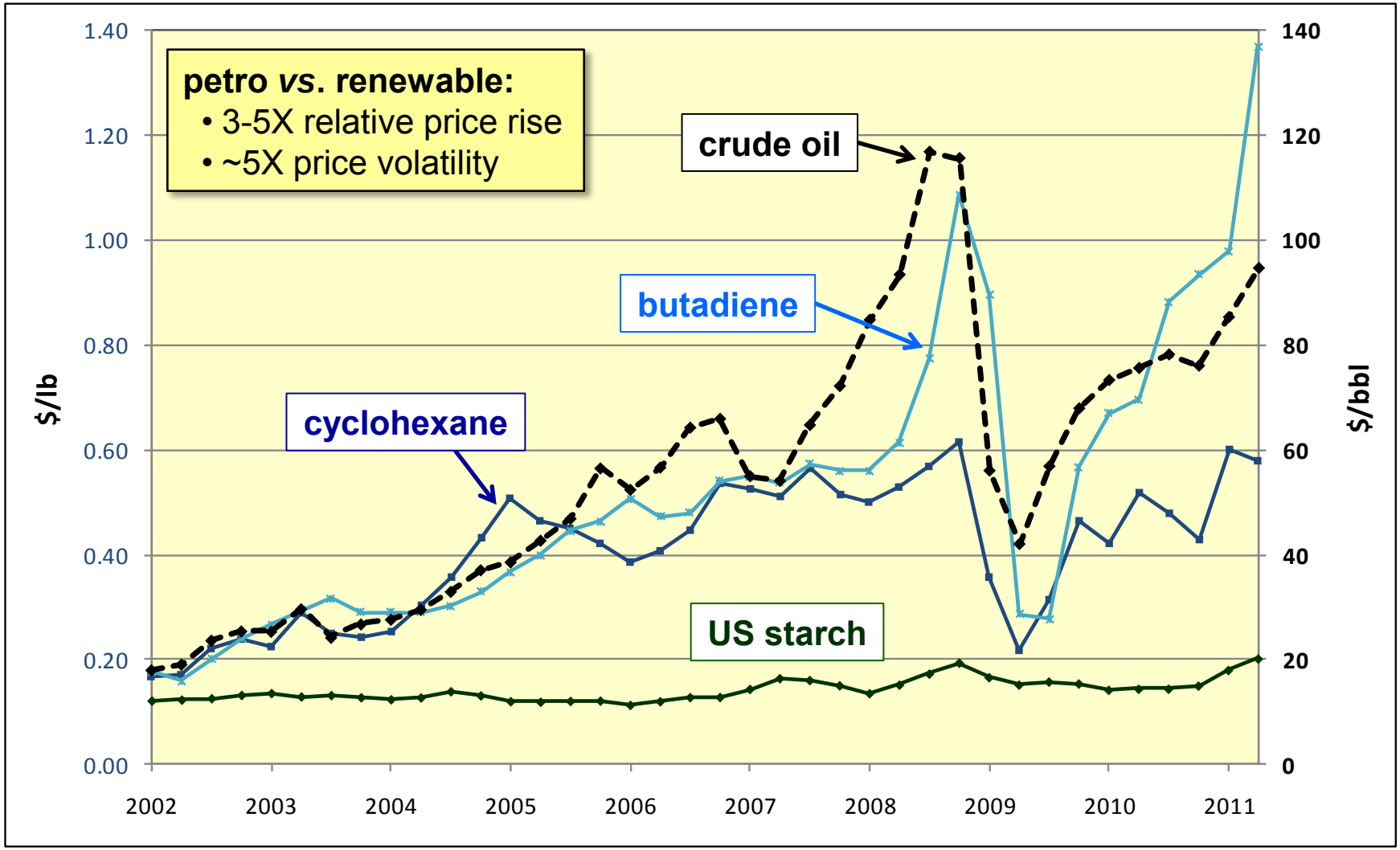
High-Throughput Catalyst R&D

- R&D team experts in high-throughput catalyst research
- Proven record of breakthrough catalyst & process development

Sustainable Cost Advantage

- Targeting below cash-cost of existing petrochemical processes
- Employ existing raw material supply chain

Renewable *vs*. Petroleum Raw Materials Prices



Rennovia ... a new path to sustainability

Risk Reduction in Renewable Chemicals Production

Raw Materials	X	Conversion Technology	X	Products
Petroleum ⇩ ***Renewable***		***Chemo-catalysis*** *vs.* Bio-catalysis		***Existing products*** *vs.* New products

- **Minimizing supply chain** risk by employing existing renewable raw materials and by producing existing large-volume products
- **Minimizing conversion risk** by utilizing chemo-catalytic process technology

Rennovia Feedstock Plan

existing carbohydrate feedstocks

existing C6 carbohydrates

Rennovia *Chemo-Catalysis Platform*

existing chemicals

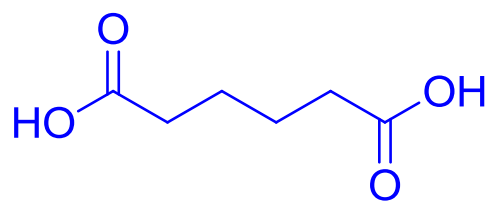
emergent lignocellulosic feedstocks

future lignocellosic carbohydrates

- Initially leverage existing carbohydrate supply chain
  - with negligible impact on consumption, *vs.* fuels
- Technology forward-compatible with emergent feedstocks

Rennovia ... a new path to sustainability

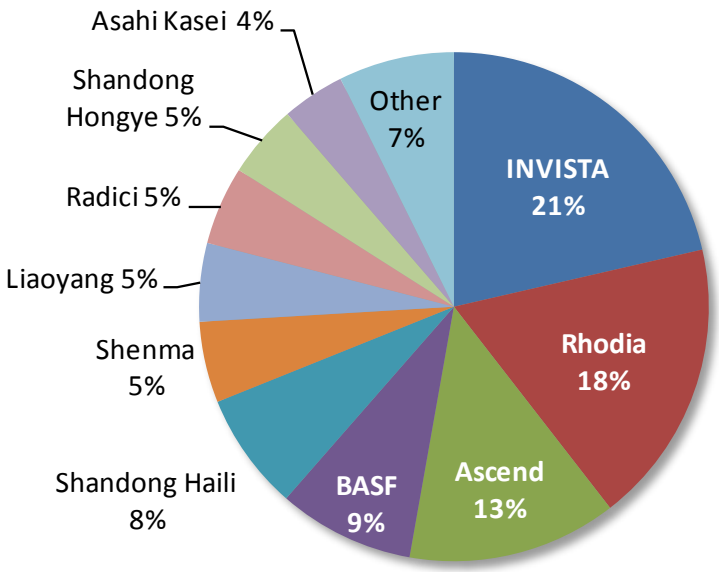
Rennovia Product #1: Adipic Acid

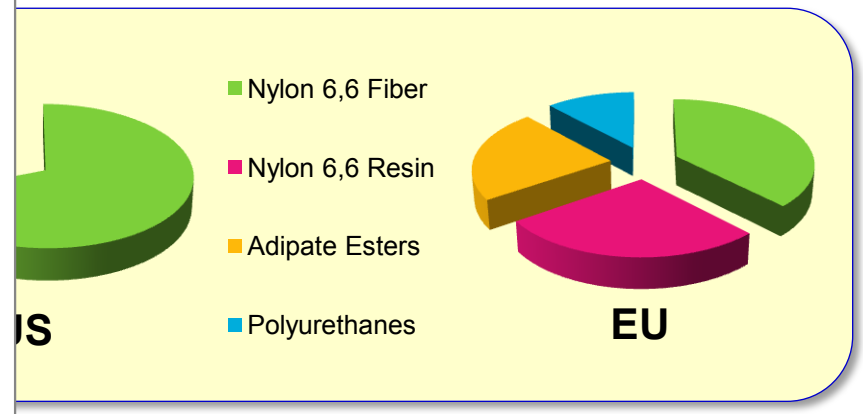


adipic acid

6.2 B lb/yr global market*

- 3-5% CAGR*
- global operating rate: 85-90%*
- recent selling price: $1.15-$1.50/lb†



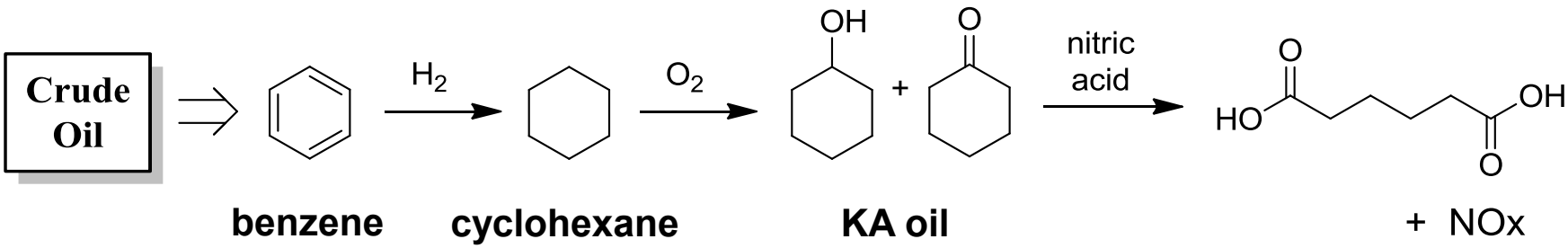


dipic Acid End Use Segments

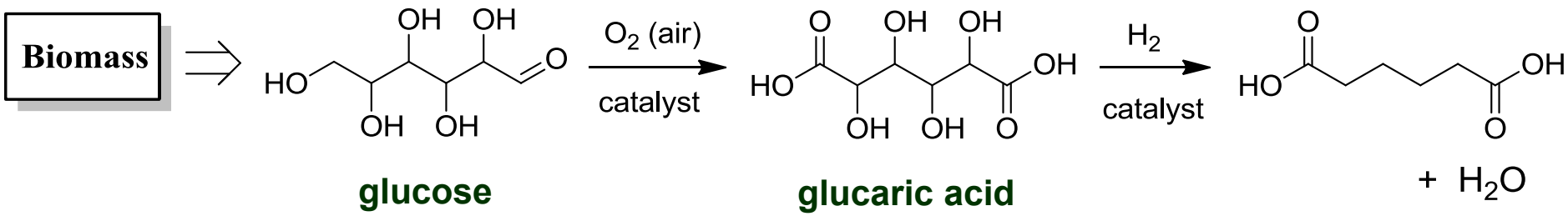
* Technon OrbiChem, 2011
† ICIS Chemicals Pricing

Petroleum *vs*. Renewable Adipic Acid Production

Current petrochemical process *via* cyclohexane:



Rennovia renewable adipic acid process:



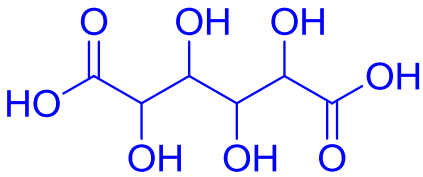
- Multiple patent applications filed
- Detailed engineering analysis → <u>below cash-cost</u> of cyclohexane process

Rennovia ... a new path to sustainability

Renewable Adipic Acid Product Family

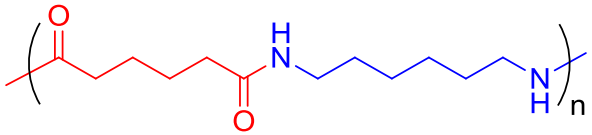
biomass

glucose →

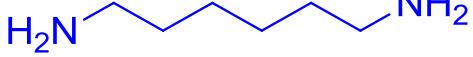


glucaric acid
emerging market

adipic acid
6.2 B lbs



nylon-6,6
5.1 B lbs

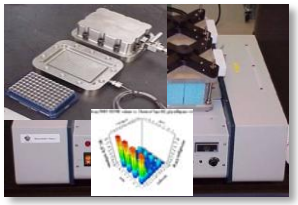


HMDA
2.9 B lbs

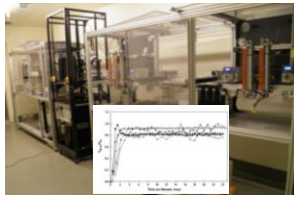
Rennovia ... a new path to sustainability

High-Throughput Catalyst R&D Infrastructure

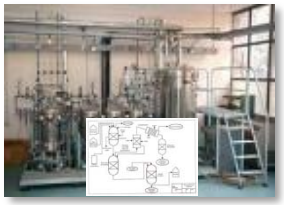
Rennovia internal development → **Leverage external resources**



HT R&D



Continuous Reactors



Lab-Pilot Scale

Commercial Demonstration

Commercial-Scale Production

World-class high-throughput catalyst R&D infrastructure

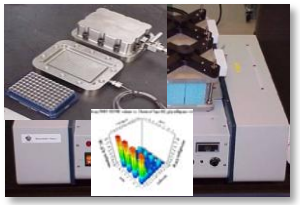
- Robotics for automated catalyst synthesis and processing in “library” format
- Multi-channel batch reactors, high-throughput analytical assays
- Software for library design, automated synthesis, screening, and data collection
- Extensive archive of catalysts and catalyst supports

Multi-Channel continuous three-phase trickle-bed reactors

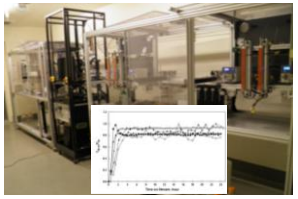
- Fully-automated reactors with continuous product collection and analysis
- Used for optimization of lead catalysts for activity, selectivity, lifetime
- Bridges high-throughput batch reactors and lab-pilot scale reactors

Rennovia Continuous Reactor Infrastructure

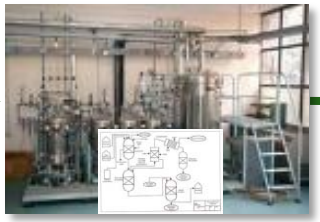
Rennovia internal development → **Leverage external resources**



HT R&D



Continuous Reactors



Lab Pilot Scale

Commercial Demonstration

Commercial-Scale Production

Lab Pilot Scale Continuous Three-Phase Trickle-Bed Reactors

- Renewable Adipic Acid Process entering ~25 lb/day continuous production
- Two primary deliverables:
  - Optimized catalysts & process conditions for commercial demonstration plant
  - Purified products for downstream product qualification

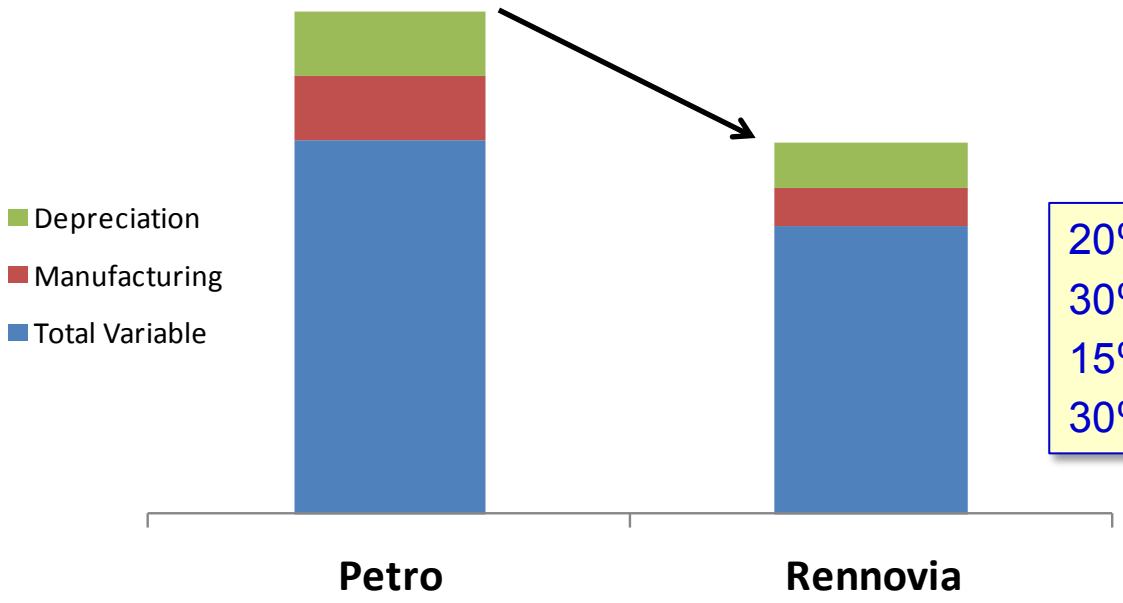
Overall Status

- High-throughput R&D enabled rapid development of initial catalysts & processes
- Patent applications filed for process, products, and catalysts
- Catalyst performance developed to viable pre-commercial target in < 1 year

Rennovia ... a new path to sustainability

Advantaged CAPEX & OPEX *vs.* Petro Adipic Acid

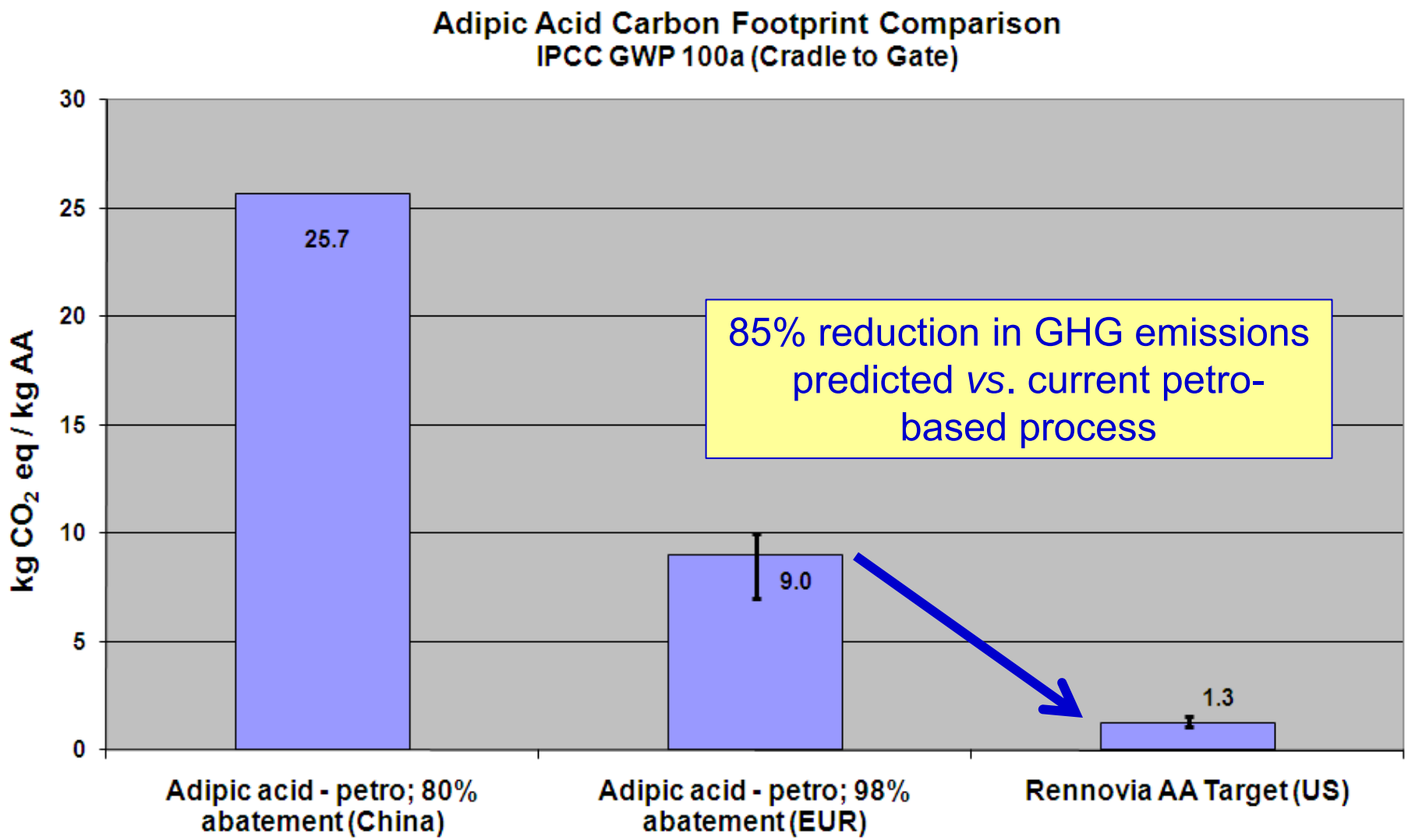
- Detailed engineering models constructed to compare Rennovia's renewable adipic acid process *vs*. the conventional cyclohexane oxidation process
- Rennovia process shows robust advantages in CAPEX & OPEX



20% lower capital
30% lower raw materials
15% lower utilities
30% lower manufacturing

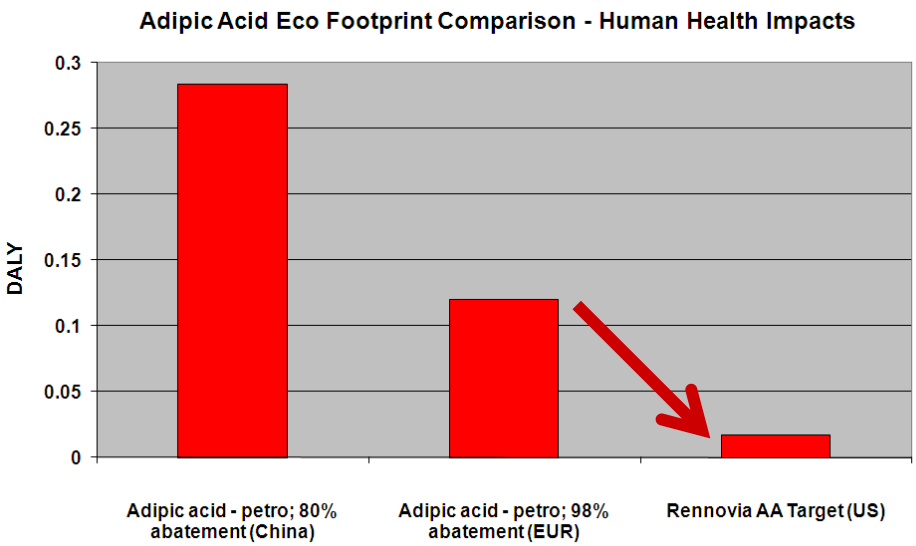
➢ ***Below cash-cost of petro process to below $50/bbl crude oil***

Life Cycle Analysis (LCA) for Rennovia Adipic Acid

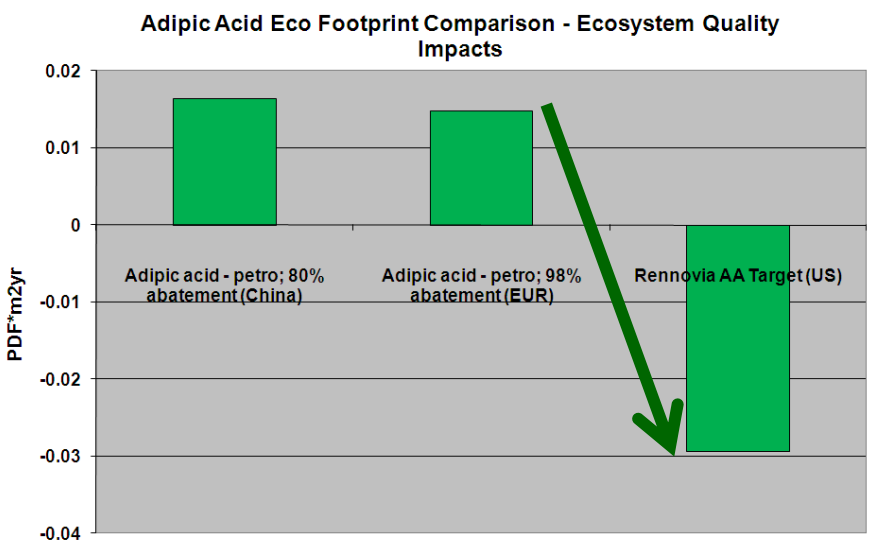


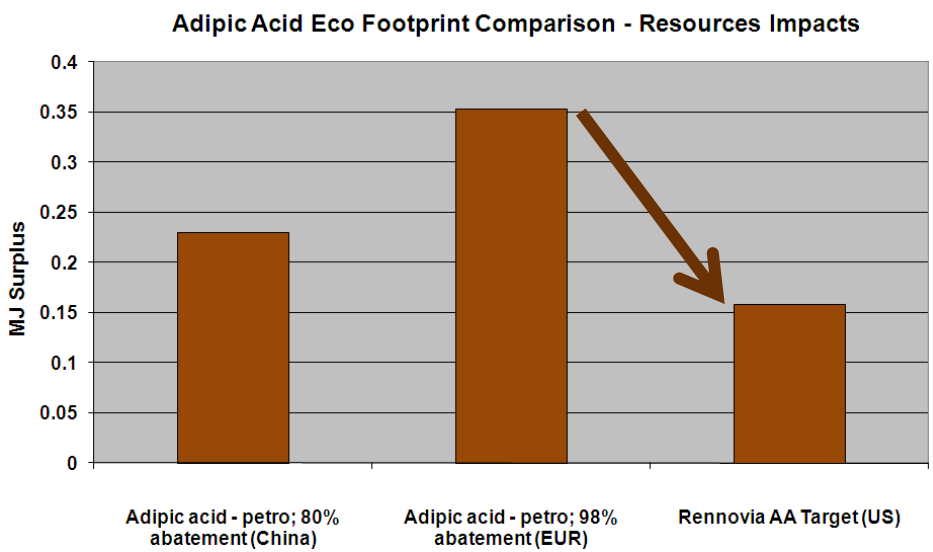
Rennovia ... a new path to sustainability

Life Cycle Analysis (LCA) for Rennovia Adipic Acid



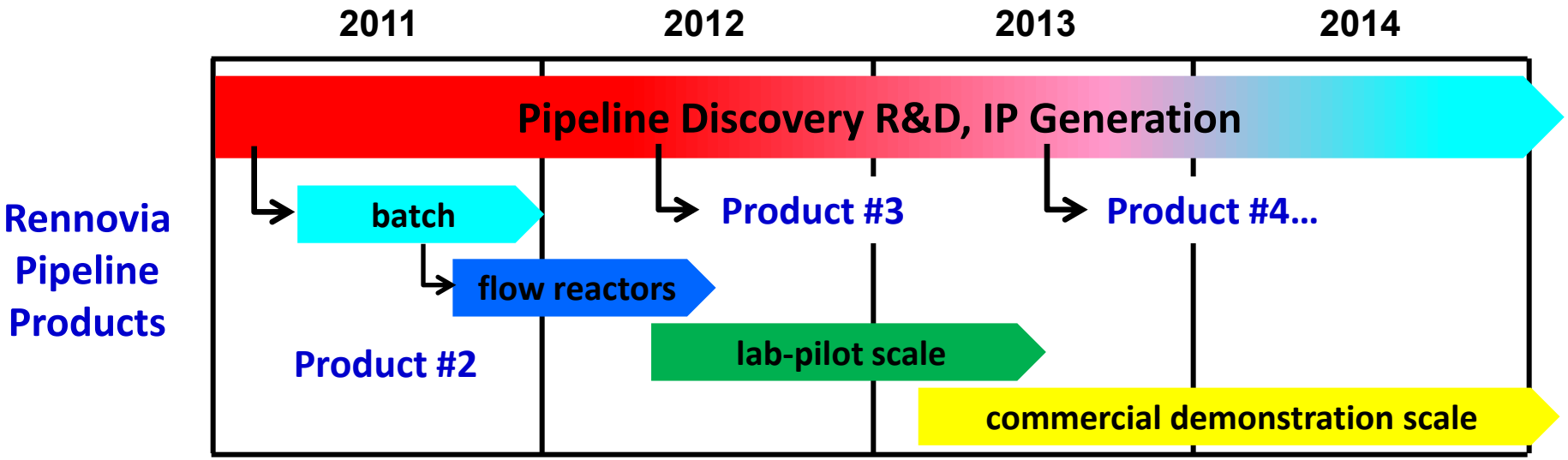
- Decreases across other eco-impacts (Eco-indicator 99 (H/A) method, cradle-to-gate):
  - **Human Health**
    - carcinogens, respiratory organics / inorganics, climate change, radiation, ozone layer
  - **Ecosystem Quality**
    - ecotoxicity, adidification, eutrification, land use
  - **Resource Depletion**
    - minerals, fossil fuels





Rennovia ... a new path to sustainability

Product Pipeline Development



- Currently in early-stage catalyst & process R&D on several pipeline products
- Product #2 in catalyst development & scale-up
- Multiple additional product targets identified
- Exploring pipeline product partnership opportunities

Summary

Renewable Chemicals

- To date, US government alternative feedstock funding has focused almost exclusively on fuels, yet bio-based chemicals are better positioned to become commercially viable, without subsidies, well before bio-fuels
- Combining the unparalleled US agricultural and chemical manufacturing infrastructures provides a historical opportunity to re-vitalize the US chemicals industry

Rennovia

- Rennovia is developing advanced chemo-catalytic processes for the conversion of bio-derived, renewable feedstocks to major-market chemical products
- These processes are designed to be readily scalable and to employ standard chemical production and purification equipment
- Rennovia's first product, adipic acid, is entering lab-pilot scale production, with targeted initial commercial production in 2015
- Rennovia is seeking partnerships across the renewable chemicals value chain, and within state and federal funding agencies, to accelerate commercial deployment